SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

Research in Space Science

SPECIAL REPORT

Number 152

TEMPERATURE VARIATIONS IN THE UPPER ATMOSPHERE

DURING GEOMAGNETICALLY QUIET INTERVALS

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June 15, 1964

CAMBRIDGE, MASSACHUSETTS 02138

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(Manuscript received June 1, 1964)

Abstract.--The drag analysis of low-perigee satellites such as Injun 3 and Explorer 17 at a time of low solar activity has revealed appreciable fluctuations in upper-atmosphere temperature during geomagnetically undisturbed days. These temperature variations are very nearly proportional to the variations in the K_p index, in contrast with the temperature variations during magnetic storms, which show proportionality with the a_p index. When $K_p < 3$, the temperature increase corresponding to a unit increase in K_p is about 40°. This corresponds to a value of $\Delta T/\Delta a_p$ close to 8°, six or seven times larger than that found in magnetic storms. Since the average value of K_p outside magnetic storms is about 2, the temperature on undisturbed days must be about 80° higher than that corresponding to $K_p = 0$. This again raises the question whether no heat source other than solar EUV is present when $K_p = 0$.

When the upper-atmosphere heating that accompanies geomagnetic disturbances was first detected from satellite drag analysis (Jacchia, 1959), use was made of the K_p index for comparison with the observed sudden increases in drag. It soon became apparent that the drag variations and the underlying temperature variations (Jacchia, 1961a, 1961b, 1963) were better related to the a_p index, of which K_p is a logarithmic function. An analysis of 38 drag perturbations on Explorer 9 (Jacchia and Slowey, 1963) showed that during magnetic storms the increase ΔT in temperature is approximately proportional to the increase Δa_p in the a_p index, apart from a 5-hour lag in the temperature variation; the coefficient of proportionality, $\Delta T/\Delta a_p$, was found to be close to 1?2. We must point out that this value relies to a great extent on a dozen major storms, inasmuch as the weight of the smaller perturbations, barely emerging above the noise level, was necessarily low.

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The Explorer 9 analysis covered drag data from March to November 1961, when solar activity was still moderately high. Owing to this fact and to the relatively low atmospheric drag (the perigee height of the satellite was, on the average, greater than 700 km), the noise level was rather high at the time. With the approaching of quiet-sun conditions the erratic fluctuations related to variable solar EUV have considerably decreased, and the availability of suitable satellites with perigee heights as low as 250 km (Injun 3 and Explorer 17) has made it possible to detect variations connected with geomagnetic activity even during "quiet" intervals, outside proper disturbances. Surprisingly, the amplitude of these oscillations is much larger than would be expected from the coefficient $\Delta T/\Delta a_p$ determined from magnetic storms; in other words, the coefficient $\Delta T/\Delta a_p$ shows a sharp increase for small values of a_p. Actually, the relation between ΔT and Δa_p departs so strongly from linearity for small values of a_p that a good relation between geomagnetic activity and temperature is obtained only by abandoning the a_p index and reverting to K_p.

To isolate the atmospheric fluctuations of geomagnetic origin, it is necessary to eliminate from the observed data the variations originating with the three other major effects:

(a) the variations caused by changes in solar EUV radiation, which are correlated with the decimetric solar flux;

(b) the "diurnal," or "day-and-night" variation; and

(c) the semiannual variation.

A model for these variations, based on 5 years of satellite-drag observations, has recently been presented by Jacchia (1964). This model gives temperature variations as a function of solar parameters, geographic location, and local time; atmospheric densities are connected with the temperature through Nicolet's (1961) model.

Temperatures derived from the drag of several satellites were reduced to standard conditions, i.e., to a standard value of the 10.7-cm solar flux, to the nighttime minimum of the diurnal variation, and to the average level of the semiannual variation. Apart from the easily recognizable peaks in correspondence with geomagnetic disturbances, all temperature plots as a function of time showed synchronous erratic fluctuations which at first sight appeared not to correlate with the a_p plot, so much so that we believed we were in the presence of a new effect unrelated to geomagnetic activity. The authors are indebted to Dr. D. Cattani for pointing out that a better correlation might be obtained by using the K_p instead of the a_p index. The results of such a comparison for Explorer 17 (1963 ι1) are shown in figure 1; figure 2 gives an intercomparison of the "quiet-day" fluctuations derived from three satellites--Explorer 8 (1960 ξ1), Explorer 17 (1963 ι1) and Injun 3 (1962 βτ2).

The quantities plotted at the bottom of figure 1 are the two-day running means of the three-hourly K_p indexes. This smoothing seemed to be necessary to bring the geomagnetic variations in line with the temperature data from Explorer 17, for which the drag was obtained from the second differences in the mean anomaly tabulated at one-day intervals. This tabular interval is the smallest that can give a reliable acceleration; it is therefore quite reasonable to assume that more rapid fluctuations than those shown in figure 1 actually exist in the temperature, just as they exist in the three-hourly K_p index.

From the data of figure 1 it appears that the temperature increase corresponding to an increase of one K_p unit is about $40°$ for K_p values between 1 and 3. Since $da_p/dK_p \approx 5$ when $K_p = 2$, we find that this temperature rise is equivalent to $8°$ per unit a_p when $a_p < 15$; this is a value six or seven times as large as the one found in magnetic storms. Since the average value of K_p on nondisturbed days is about 2, we can see that even in those conditions the temperature of the upper atmosphere is about $80°$ higher than that corresponding to $K_p = 0$. This could again raise the question whether no heat source other than solar EUV is really present when $K_p = 0$, as some recent papers (Nicolet, 1963; Jacchia, 1964) seem to suggest.

There is little doubt that in magnetic storms the temperature variations correlate much better with the a_p than with the K_p index. This is shown by the great differences in the temperature increase observed in individual storms, which reach a factor of 10, while the K_p index in magnetic storms ranges only from 5 to 9 at maximum. In addition there is the shape of the temperature maximum, generally quite sharp, just as in the a_p plot, while the K_p diagram in storms usually has a much broader peak.

It is perhaps premature to draw any conclusion on the variation of $\Delta T/\Delta a_p$ with a_p--whether it gradually drops from its large values for small values of a_p, or whether we have two distinct regimes, one for undisturbed days and another for magnetic storms proper. In any case the relation between ΔT and Δa_p in storms will be affected, because the zero level for ΔT will have to be taken generally lower than had been previously assumed in the extrapolation to $a_p = 0$.

It must be pointed out that, besides noise of solar origin, there is another reason why these oscillations on undisturbed days probably could not have been discovered at sunspot maximum. When more energy from solar EUV is available, the relative effect of added energy variations must be smaller--unless their zero level and amplitude are also proportionally increased. Since the variation $\partial\rho/\partial T$ of the density with temperature at all levels is larger the lower the temperature, temperature oscillations of a given amplitude are more conspicuous when the atmosphere is cooler.

Acknowledgment

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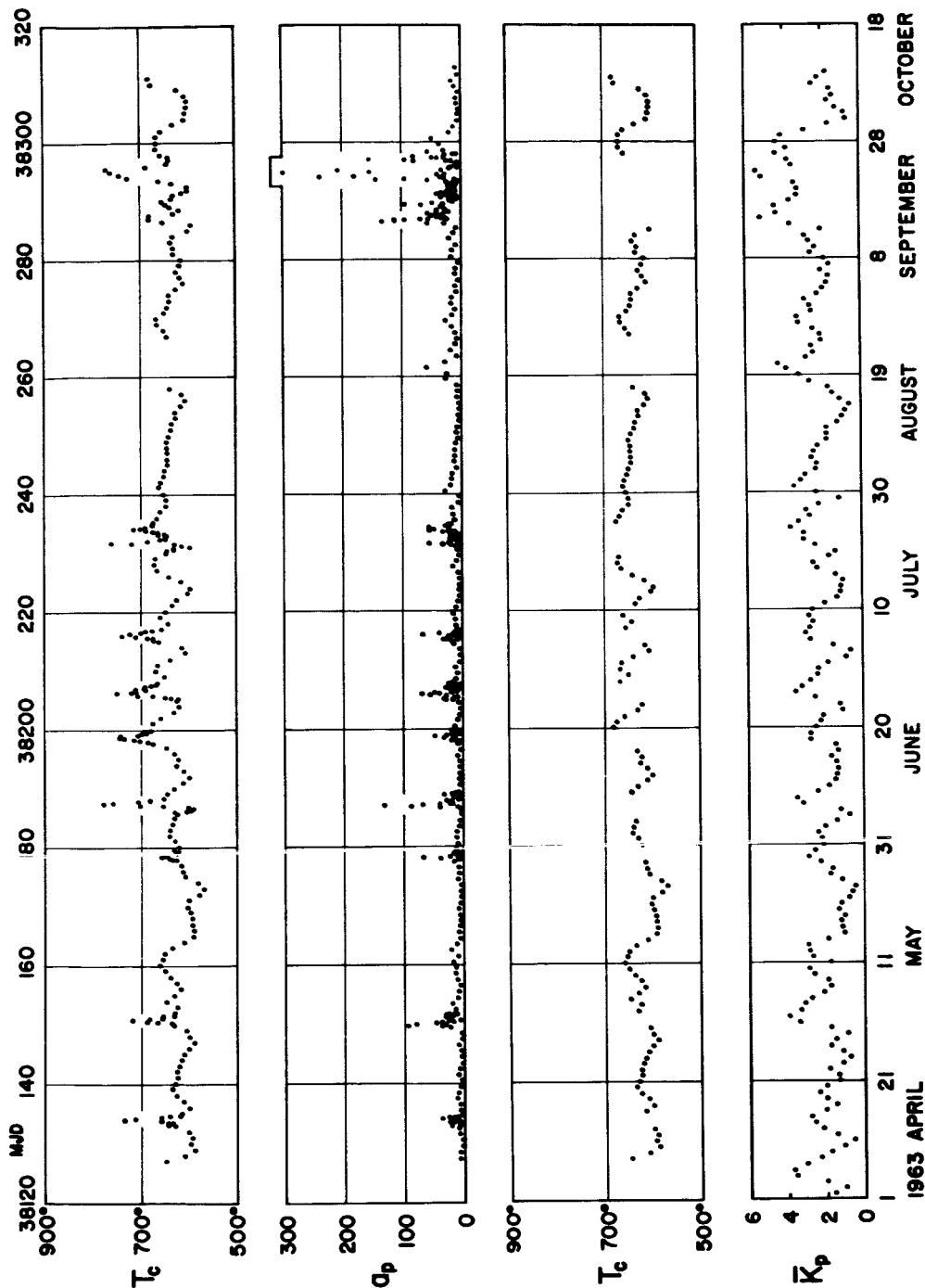   Geophys. Res., vol. 68, pp. 6121-6144.

Figure 1.—Temperatures above the thermopause derived from the drag of the Explorer 17 Satellite (1963 ζ1), reduced to standard conditions of local time and solar activity and freed of the semiannual effect (T_c). The plot at the top is complete and may be compared with the a_p plot (second strip) for the variations during magnetic disturbances. In the third section the temperatures corresponding to disturbed days have been removed to aid comparison with the K_p plot (two-day running means of K_p) in the bottom section. The average perigee height of Explorer 17 is 270 km.
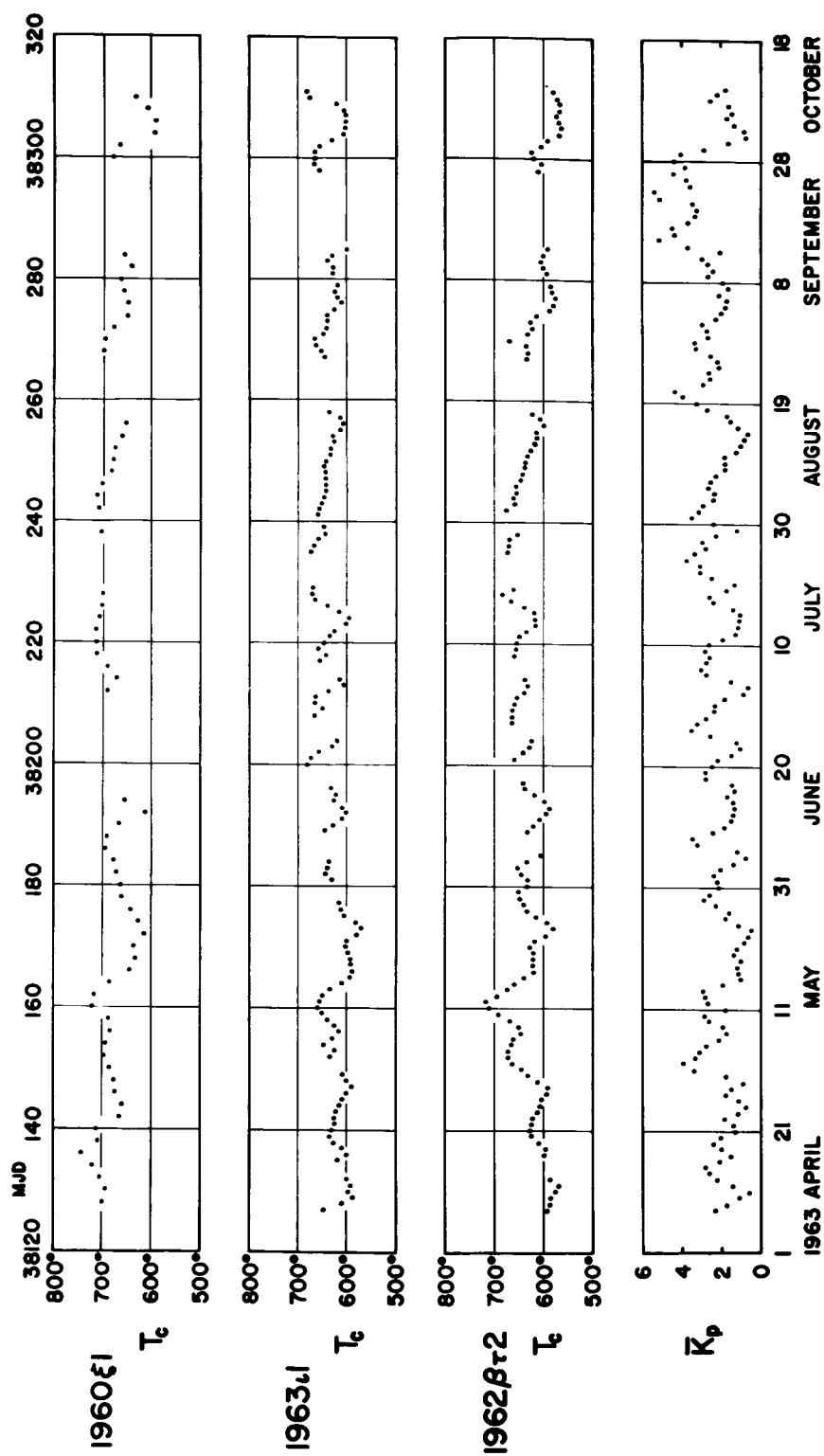
Figure 2.—Temperatures as in figure 1, third section, from the drag of Explorer 8 (1960 ξ1, perigee height 426 km), Explorer 17 (1963 ι1, perigee height 270 km) and Injun 3 (1962 βτ2, perigee height 250 km), compared with two-day running means of the K_p index.